The wetlands of the Lake Carey catchment, northeast Goldfields of Western Australia, with special reference to large branchiopods

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Abstract

After significant rains, many areas of the Australian arid-zone contain numerous wetlands and support a diverse aquatic fauna; an example is Lake Carey and environs. Wetlands comprise 13.6% of the Carey catchment of nearly 6000 km^2. Besides the large salina of Lake Carey (12.5% of catchment), there are many wetland types, including in order of total size: gypsum pans, samphire pans, salt pans, vegetated pans, red clay pans, creek pools and dams. Many of the smaller sites contain at least some water in late summer/autumn, and all are filled episodically to capacity at widely spaced intervals. Salinity is the most important factor distinguishing between sites, followed by turbidity and hydroperiod. Zooplankton and macroinvertebrates are mainly of widespread inland species, with coleopterans the most diverse, many odonatans, hemipterans and dipterans and a restricted fauna of oligochaetes, ephemeropterans, trichopterans and molluscs. The large branchiopod fauna is relatively diverse and comprises 12 anostracans in three genera (*Branchinella, Streptocephalus, Parartemia*), six clam shrimp in six genera: *Lynceus* (Laevicaudata) and *Caenestheria, Caenestheriella, Eocyzicus, Limnadia, Limnadopsis* (Spinicaudata)) and at least one notostracan (*Triops*). Almost all are widely distributed, though with many restrictions as to habitat type in the Carey wetlands. Co-occurrences within the orders, especially within the genus *Branchinella* are common.

Keywords: wetland typology, zooplankton, macroinvertebrates, Anostraca, Laevicaudata, Spinicaudata, Notostraca.

Introduction

In recent decades there have been numerous works in Australia identifying wetlands, classifying them and making inventories of their flora and fauna (*e.g.*, see McComb & Lake 1988; Pressey & Adam 1995; Roshier & Rumbachs 2004; Pinder *et al.* 2004). The majority have been strong on typology, often aided by satellite imagery and GIS, but information on flora, and especially fauna has been scant. Notable exceptions to this for the arid-zone include southern Carnarvon Basin and Wheatbelt studies in Western Australia (Halse *et al.* 2000; Keighery *et al.* 2004), the ARIDFLO program on the streams and associated lakes of the Lake Eyre Basin (Costelloe *et al.* 2004), and the Paroo wetlands in northwestern New South Wales and southwestern Queensland (Kingsford & Porter 1999; Timms 1999; Timms & Boulton 2001). In these studies extensive data are available on plants and most animal groups. The major environmental features influencing the biota of these wetlands are salinity, hydroperiod and turbidity (Timms & Boulton 2001; Pinder *et al.* 2004).

Invertebrates of these arid-zone wetlands are surprisingly diverse. The southern Carnarvon Basin has 490+ species, the southwest Western Australian wetlands have almost 1000 species and the Paroo 210+ (Halse *et al.* 2000; Timms & Boulton 2001; Pinder *et al.* 2004). Many species occur widely across the inland, but each area has its endemics, especially among the crustaceans. Large branchiopods (Anostraca, Laevicaudata, Spinicaudata, Notostraca) although recorded in most studies, have been thoroughly assessed only in the Paroo, where some 30+ species are known (Timms & Sanders 2002; Timms & Richter 2002), making it a 'hot spot' for diversity in Australia and indeed the world (Belk 1999).

In Western Australia, although detailed information on wetlands is available for large areas (see above), the goldfields of the inland are poorly known. Limited data on wetland types and their fauna are available in numerous unpublished reports to various mining companies (e.g., Chaplin & John 1999; Ward 1999) and also in a few published papers, which mainly concentrate on spectacular response of some waterbirds to wetland fillings (*e.g.*, Burbridge & Fuller 1982). A general assessment of the filling-drying cycle of the small Lake Arrow near Kalgoorlie provide some data on the waterbird use of one wetland and on its invertebrates, including large branchiopods (Chapman & Timms 2004). On a wider scale, there is scant information on large branchiopods for the state, except for a broad scale taxonomic study of anostracans (Timms 2002), old records of clam and shield shrimps (*e.g.*, Wolf, 1911 on *Limnadia badia*, Linder, 1941 on *Branchinella apophystata*) and a detailed assessment of the large branchiopods in gnammas (Timms, this volume).

Lake Carey is one of many large salinas on paleodrainage systems in inland Western Australia (Van de Graaf *et al.* 1977). It is lies at 29° 00'S and 122° 20'E, 220 km ENE of Kalgoorlie and is ca 750 km^2 in area with a catchment of 5220 km^2. The lake and associated wetlands fill episodically usually after intense cyclonic rains in late summer, though lighter rains at other times may input some water into the wetlands. Like many arid-zone areas, drainage in the catchment of the lake is poorly organised so that there are innumerable wetlands following significant rainfalls. Representatives of these wetlands have been studied for two mining companies (Coleman *et al.* 2004, 2005.). This paper is based on these two studies and aims to provide a typology of wetlands of the Lake Carey catchment, an assessment of their physicochemical features and invertebrates. Special attention will be given examination of the large branchiopods of this remote and unstudied area.

Methods

The variety of wetlands in the Carey catchment was first assessed on the ground on field trips in February and April 2003 and later the variety and the extent of each wetland type was determined by analysis of a digital aerial photograph (at 450 dpi) using the program ArcView 3.2 at a scale of 1:10,000 and ER Viewer. The area was loosely divided into drainage lines and associated pans and channels and sometimes further into blocks of similar types *e.g.*, salinas, freshwater uplands, etc. The pans and channels were scored according to size and type – red clay pans, gypsum salina, salty pan, samphire pan, vegetated pan, vegetated drainage line, vegetated drainage line with channel. These were ground-truthed against known examples of each. Earthern man-made dams were easily detected on the aerial photographs and on the ground.

Analysis of the wetlands was limited by several potential generic errors:

- Falsely identifying areas as wetlands, such as wind erosion scalds and vehicle turnouts (particularly in red clays)
- Misrepresenting the salinity of the wetland – categories of salinity (gypsum, saline, fresh water) was assigned by location in the catchment.
- Underestimation of small vegetated wetlands – one wetland sampled could not be identified on the aerial photograph.
- The variety of vegetated wetlands seen on the ground could not be determined on the aerial photograph.
- It was not possible to determine the period and frequency of inundation from the aerial photograph.

Field trips were made to the study area on 15–17 February 2003, 14–17 April 2003, 10–13 March 2004 and 4–7 April 2004. Each trip was in response to significant rainfall, though some wetlands did not fill on each occasion, or were not studied for logistic reasons.

At each wetland visit the following physicochemical features were measured: depth, turbidity (with a NTU tube), conductivity, and pH (both with a TPS Model MC-81 meter). Zooplankton was collected with a net of mesh size 159 ìm mounted on a pole and with a rectangular aperture 30 x 15 cm. Collections were made for 1 minute over a 10 m transect usually in the deepest part of each site (if plankton was sparse time and distance was doubled or tripled). In the laboratory, species were identified and a random sub-sample of 200 individuals counted. The remainder of the subsample was scanned for rare species and these added to the count as 0.1%. Macroinvertebrates were sampled with a rectangular dip net of aperture 30 x 15 cms and mesh size of 1 mm. This was swept through a 10m x 1m transect in two minutes to get a semiquantitative sample and sweeping continued for 15 minutes to catch uncommon species. Species present in both samples were identified using numerous different keys and the voucher specimens at the research laboratories of the Department of Conswervation and Land Management at Woodvale. Those in the 2-minute samples were enumerated, but their only presence was noted for the 15 minute samples. Large branchiopods occurred in both zooplankton and littoral macroinvertebrate samples, with most in the 15 minute macroinvertebrate net sweeps.

Mesh sizes of both nets were larger than used other survey work in Western Australia (Halse *et al.* 2000; Keighery *et al.* 2004), meaning some smaller invertebrates were probably missed, but not large branchiopods, the focus of this study.

Similarity of zooplankton and littoral assemblages at each site were analysed using multivariate techniques (Clarke & Warwick 2001). Percentage abundance of zooplankton and absolute abundance of littoral invertebrates from the two minute collections with additions from the 15 minute collections were each log transformed Data were then ordinated with non-metric multidimensional scaling using the SIMPER routine in PRIMER.

Results

The wetlands

Besides the large Lake Carey, nearly 1600 wetlands totalling 6720 ha were identified in the Carey catchment (Table 1). Gypsum pans were the most numerous (42% of total) and also by far the greatest in area (65%). Red clay pans were the next most numerous (26%), but because of their small size their combined area was small (2% of the total catchment). Vegetated pans also tended to be relatively numerous and small, particularly if the error in missing small ones is taken into account. Creek channels were not included in the calculations of areas, but if they averaged <10m wide as suggested by visual inspection of a few, then their combined areas are also small and, like the dams, contribute <0.1% of wetland areas. The non-red pans distinguished from aerial photographs could not be ground-truthed with any wetland type.

There are little data on hydroperiods for these wetlands, but field experience during 2003 and 2004 suggest the small pools in some creek channels and many dams retain water the longest and that many of the gypsum pans, salt pans and samphire pans rarely fill and when they collect a little water they soon dry. Many red clay pans and vegetated pans retain water for many weeks to a few months after significant rainfall.

Table 1

Wetlands of the Lake Carey catchment

size-frequency distribution	vegetated creek channels (km)	saline creek channels (km)	large salina	red clay pans	gypsum pans	salt pans	samphire pans	vegetated pans	non-red pans	dams	Totals
min. area 0.1 ha				377	512	80	3	72	70	20	1134
1 ha				38	99	38	14	108	30	10	337
10 ha				5	55	14	7	24	2		107
100 ha					7	4			1		12
1000 ha					3		1				4
75000ha			1								
Total numbers			1	420	676	136	25	204	103	30	1597
Total area (km or ha)	19.1	22.0	75000	125.7	4400.2	596.0	1084.3	355.2	157.0	12.0	81,720
% of Carey catchment			12.5	0.02	0.7	0.1	0.2	0.06	0.03	0.002	13.6

Wetlands studied are listed and illustrated in Coleman *et al.* (2004, 2005) and their positions are shown in Fig 1. Altogether 34 wetlands were visited, though many were not sampled on each field trip, due to logistic or time constraints, or sites being dry.

Physicochemical features

Some parameters are distinctive for the wetland types (Table 2). There was a marked dichotomy in TDS, with three saline types and the remainder fresh, though among the later, gypsum pans had a slightly elevated mean TDS. All the saline sites had clear waters, but with some elevation in turbidity in Lake Carey, while three of the fresh water sites (dams, claypans and turbid samphires) had markedly turbid waters. Most sites had alkaline waters with a pH 8.0 to 8.6, but vegetated pools usually had much lower pH. Not surprisingly dams were the deepest wetlands, though some of the gypsum pans were >0.5 m deep; by contrast claypans and saline creeks tended to be the shallowest (<0.2m).

Many sites varied between sampling trips and between years, none more so than site 2 (Standpipe Ck pool). Depending on rainfall and subsequent flow, it had characteristics of a freshwater creek pool, a samphire pan, or a salt water creek pool. Site 10, a small pool, also hardly fitted the classification – it has many physiochemical characteristics of a vegetated pool, but there was no vegetation.

Zooplankton

At least 28 species live in the Carey wetlands (Table 3); *Boeckella triarticulata*, *Mesocyclops brooksi* and *Daphnia carinata* s.l. dominated in freshwater sites, while *Meridiecyclops platypus*, *Apocyclops dengizicus*, *Diacypris* spp., *Cyprinotus edwardi* and *Repandocypris austinensis* dominated in saline waters. Some species occurred rarely, including *Latonopsis brehmi* at site 7 in both 2003 and 2004, *Moina baylyi* in Lake Carey in 2004 and *Trigonocypris globulosa* at site 22 in 2003.

Multivariate analysis of the February 2003 samples (Fig. 2a) separated saline sites (6,15,18,21) as a separate group, the turbid sites (mainly claypans, dams and turbid samphire swamps) as another (1,8,9,11,14,19, 22), the clearer water sites (included vegetated sites and freshwater creek pools) as another (3, 5, 7, 12), with site 2 as an intermediary and site 10 as an outlier. Similar analysis on a largely different set of wetlands sampled in March 2004 (Fig. 2b), point to a distinct saline group (comprising various Lake Carey sites (25,26,30,32,34) and saline creek pools (20,21), and wide spacing of the other sites, with site 2 closest to the saline sites.

Table 2

Some physicochemical features of the wetland types

Wetland type	TDS (gL^{-1}) mean ± SE	Turbidity (NTU) mean ± SE	pH mean ± SE	Depth (m)
Dams	0.20 ± 0.14	437 ± 37	8.05 ± 0.15	0.90 ± 0.10
Freshwater creek pools	0.43 ± 0.34	92 ± 80	8.56 ± 0.31	0.40 ± 0.10
Vegetated pools	0.23 ± 0.19	194 ± 71	7.43 ± 0.31	0.31 ± 0.06
Clay pans	0.20 ± 0.05	450 ± 19	8.20 ± 0.15	0.15 ± 0.04
Turbid samphires	0.32 ± 0.20	416 ± 45	8.08 ± 0.81	0.26 ± 0.13
Gypsum pans	1.5 ± 0.8	16 ± 4	8.66 ± 0.16	0.65 ± 0.18
Salt creek pools	53.3 ± 9.4	8 ± 3	8.57 ± 0.23	0.18 ± 0.04
Salt pans	47.4 ±11.0	11 ± 4	8.43 ± 0.10	0.21 ± 0.12
Salt lake	45.3 ± 14.4	58 ± 19	8.39 ± 0.14	0.31 ± 0.03
Site 2	12.7 ± 7.6	27 ± 13	8.97 ± 0.16	0.45 ± 0.15

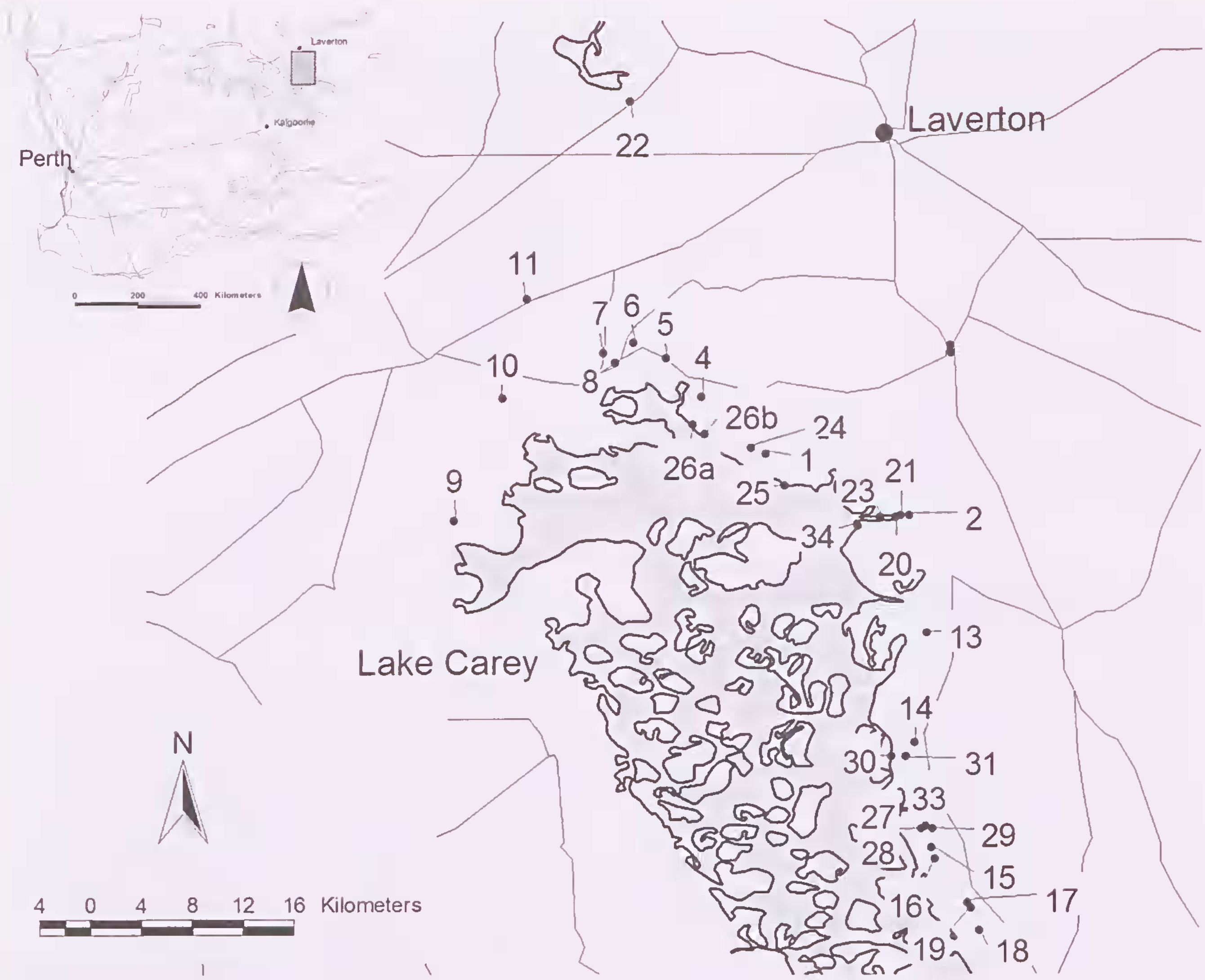

Figure 1. Map of Lake Carey and its catchment, showing the sites studied. Lake shore and islands solid lines, roads and tracks dashed. Code to sites: 1 = Ti Tree Dam, 2 = Standpipe Ck, Bindah Rd, 3 = Wynditch Ck, Mt Bold Station, 4 = a small creek, 5 = Mosquito Swamp, 6 = a salty creek, 7 = a grassed wetland near Mt Margaret, 8 = a clay pan near Mt Margaret; 9 = clay pan on Horses Head, 10 = pool near Cement Ck, 11 = a big clay pan, 12 = Wynditch Ck at road crossing, 13 = a samphire flat, 14 = Sunrise Dam, 15 = a playa South Sunrise, 16 = a playa, 17 =North Camel Playa, 18 = Camel Playa, 19 a canegrass swamp, 20 = Standpipe Ck lower, 21 = Standpipe Ck upper, 22 = The Boats, 23 Standpipe Ck mouth, 24 = Wallaby samphire flat, 25 = Wallaby Mine discharge into Lake Carey, 26 Salinaland of Lake Carey, 27 = s samphire swamp, 28 = a 'deep' gypsum lake, 29 = a samphire swamp, 30 = Old Sunrise discharge into Lake Carey, 31 = a gypsum pond, 32 = Sunrise discharge into Lake Carey, 33 = a gypsum pan, 34 = Lake Carey near Standpipe Ck.

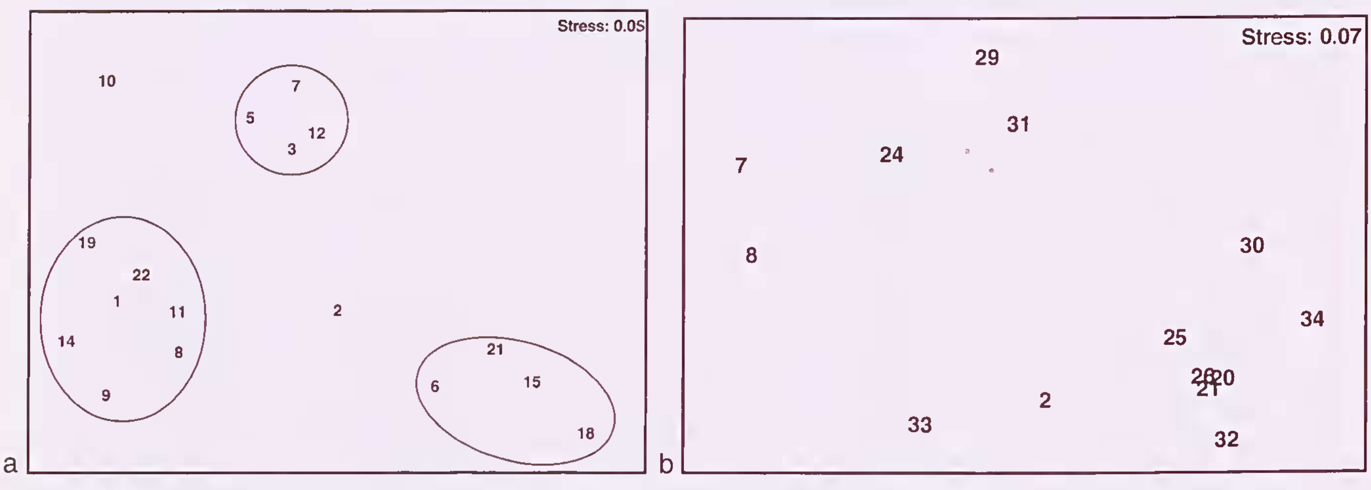

Figure 2. Ordination diagrams of wetlands based on zooplankton assemblages. (a) February 2003 collections. (b) March 2004 collections.

Table 3

Zooplankton in Carey wetlands

Group	Species	Feb-03 22 sites	Apr-03 17 sites	Mar-04 14 sites	Apr-04 13 sites
Rotifer	*Brachionus plicatilus* (Muller)	4	4		1
	Filinia sp.	1			
Copepoda	*Boeckella triarticulata* (Thomson)	8	9	3	4
	Boeckella sp. near *triarticulata* (Thomson)	1	2	1	
	Calamoecia near *ampulla* (Searle)	1	1		
	Apocyclops dengizicus (Lepeschkin)	3	1	3	1
	Australocypris similis Morton	9	8	2	2
	Meridiecyclops platypus Feirs	1		3	2
	Mesocyclops brooksi Pesce et al.	5	8	1	1
Cladocera	*Diaphanosoma unguiculatum* Gurney	3			
	Latonopsis brehmi Petkovski		1	1	
	Daphnia carinata s.l. King	7	5	3	3
	Daphnia near *projecta* Hebert	4	1	1	
	Ceriodaphnia sp.				1
	Moina baylyi Forro				4
	Moina micrura Kurz	11	8	2	
	Moina australiensis Sars	3	3	2	2
	Macrothrix carinata (Smirnov)		1	1	2
	Alona spp.				3
	Chydorus sp.				1
Ostracoda	*Bennelongia* spp.	1	7	3	
	Cyprinotus edwardsi McKenzie	3	5	3	3
	near *Cypridopsis* sp.	1			
	Diacypris spp.		5	6	6
	near *Heterocypris* sp.	3	1	2	2
	Repandocypris austinensis Halse & McRae	1	2	6	5
	Trigonocypris globulosa De Deckker		1		
	unknown ostracod			1	1

Macroinvertebrates except Large Branchiopods

More than 61 species of non crustacean macroinvertebrates live in the Carey wetlands (Table 4); the list would have been longer had a smaller net mesh size been used and groups such as chironomids and water mites been identified further. The most common species were *Austrolestes aridus, Micronecta* sp, *Agraptocorixa* spp., *Anisops* spp., *Berosus* spp. and *Eretes australis.* The scarcity of ephemeropterans, trichopterans, and gastropods is notable, as is the few records of many species, particularly coleopterans.

Multivariate analysis of the February 2003 samples indicate a compact saline group (6,13,15,16,17,18,20,21) and many small groups (Fig. 3a), including claypans (8,9,11), vegetated and samphire pools (5,7,19), dams (1,14), freshwater creek pools (3,4,12) with sites 2,10 and 22 as ungrouped. The March 2004 results on a largely different set of wetlands suggested a compact saline groups with distinction between Lake Carey sites (25,26,30,32,34) and saline creek sites (20,21), a grouping of gypsum pans (28,29,31,33) and with site 2 as an outlier and sites 24, 7 and 8 on the fringes of the other fresh water sites.

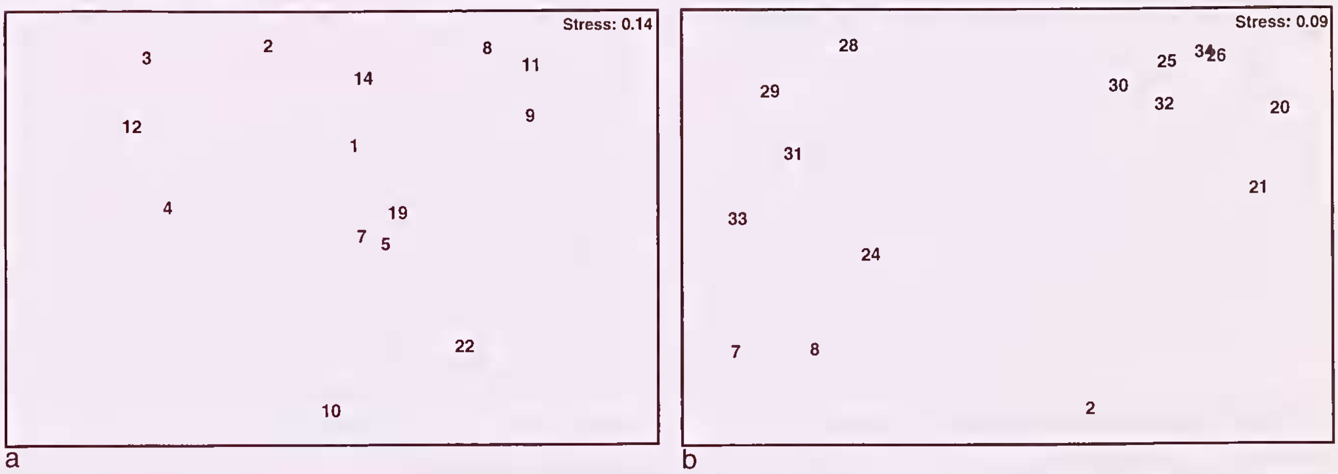

Figure 3. Ordination diagrams of wetlands based on littoral invertebrate assemblages. (a) February 2003 collections with saline sites omitted as they plot on top of each other, (b) March 2004 collections.

Table 4

Macroinvertebrates other than crustaceans in Carey wetlands

Group	Species	Feb-03 22 sites	Apr-03 15 sites	Mar-04 16 sites	Apr-04 14 sites
Oligochaeta	unidentfied species		1		
Insecta:Ephemeroptera	*Cloeon* sp.		1		
Insecta: Odonata	*Austrolestes* aridus (Tillyard)	2	6	2	4
	Xanthoagrion erythroneurum (Selys)		2		1
	Diplacoides bipunctata (Brauer)		3	1	2
	Hemianax papuensis Burmeister		1	3	3
	Hemicordulia tau (Selys)	3	5	7	9
	Trapezostigma loewii (Kaup)	2		5	4
Insecta: Hemiptera	*Micronecta* sp.	14	11	2	4
	Agraptocorixa eurynome Kirkaldy	5	1	4	4
	Agraptocorixa parvipunctata Hale	12	12	1	2
	Anisops calcaratus Hale	1	5		
	Anisops gratus Hale	14	10	4	7
	Anisops thienemanni Lundbald	8	8		3
	Anisops stali Kirkaldy	9	5	3	6
	Ansiops sp.	3			
Insecta: Trichoptera	*Triplectides australicus* Banks		2		
Insecta: Coleoptera	*Allodessus bistrigatus* (Clark)	11	6	2	3
	Antiporus gilberti (Clark)	1	1		3
	Bagous sp.	1		1	
	Berosus approximans Fairmaine	3	2		1
	Berosus australiae Mulsant & Ray	2	3	2	1
	Berosus macumbensis Blackburn	1			
	Berosus munitipennis Blackburn	3			
	Berosus nutans (MacLeay)	11	2	3	2
	Berosus spp. larvae			4	7
	Chostonestes gigas (Boheman		2		
	Copelatus ferrugineus Sharp	1	1		
	Copelatus melanarius Sharp		1		
	Cybister tripunctatus (Olivier)	2	2		
	Dineutus australis (Fabricius)	2			1
	Enochrus maculiceps (Macleay)	4	2		1
	Eretes australis (Erichson)	11	7	1	6
	Haliplus sp.	2	1		1
	Hyphydrus elegans (Montrouzier)	1			
	Hydrophilus brevispina Fairmaire	1			
	Liodessus gemellus (Clark)		1		
	Limnozenus zealandicus (Broun)	1	3		
	Macrogyrus australis Brulle				
	Megaporus howitti (Clark)	2			1
	Megaporus ?nativigi Mouchamps		1		
	Necterosoma penicillatum (Clark)	2	1		3
	Rhantus suturalis MacLeay	2	1		
	Spercheus platycephalus MacLeay		2		
	Sternolopus immarginatus Orchymont	2			
	Sternopriscus multimaculatus (Clark)	2	3		
	unidentified Sciritidae larvae	5	1		
	unidentified beetle				1
Insecta: Diptera	unidentified Chironomini	10	6	3	1
	unidentified Tanypodinae	5	10	2	3
	unidentified Tanytarsini		3	1	1
	Aedes sp.	4	3		
	Anopheles sp.			1	1
	Culex sp.	2	1		1
	unidentified Ceratopogonidae		1		2
	unidentified Tabanidae		4		
	unidentified Stratiomyidae				1
	unidentified dipteran larva (maggot)				1
Arachnida: Hydracarina	unidentified Hydrocarina	4	3	1	1
Mollusca: Gastropoda	*Glyptophysa* sp.	4	1		
	Isidorella sp.	2	3	1	1
	unidentified gastropod		1		

Table 5

Large branchiopods in Carey wetlands

Species	No. of records	TDS range (mgL^{-1})	TDS mean (mgL^{-1})	Turbidity range (FTU)	Turbidity mean (FTU)
Branchinella affinis Linder	14	0.02 – 1.15	0.41	5 – 500	128
Branchinella australiensis (Richters)	9	0.02 – 4.2	0.94	20 – 500	248
Branchinella denticulata Linder	1		0.12		500
Branchinella frondosa Henry	7	0.02 – 4.2	0.61	5 – 60	23.8
Branchinella halsei Timms	2	0.06 – 0.12	0.09	400 – 500	450
Branchinella nicholsi Linder	1		0.57		45
Branchinella occidentalis (Dakin)	1		0.06		500
Branchinella proboscida Henry	6	0.04 – 0.5	0.14	50 – 500	392
Branchinella simplex Linder	6	12.8 – 62	27.1	5 – 100	72.5
Streptocephalus sp.	1		1.2		30
Parartemia n. sp. g	5	8 – 51	32.5	0 – 30	11
Parartemia n. sp. x	15	22 – 105	49.5	5 – 180	54
Caenestheria dictyon (Spencer & Hall)	9	0.06 – 18.1	2.6	5 – 400	108
Caenestheriella packardi (Brady)	19	0.02 – 4.3	0.67	5 – 500	241
Eocyzicus sp.	14	0.08 – 18	5.0	5 – 500	95
Eulimnadia dahli Sars	4	0.02 – 1.2	0.33	5 – 350	294
Limnadopsis birchii (Baird)	2	0.12 – 1.2	0.66	30 – 500	265
Lynceus sp.	1		0.02		10
Triops 'australiensis' form a	14	0.02 – 4.2	0.55	5 – 500	429
Triops 'australiensis' form b	10	12.8 – 93	33.4	5 -180	76

Large Branchiopods

Nineteen species of large branchiopod crustaceans were encountered, comprising 12 anostracans, six clam shrimp (one laevicaudatan, 5 spinicaudatans) and at least one shield shrimp (Table 5). The most common anostracans were *Branchinella affinis* and *B. australiensis* in fresh waters and *Parartemia* n.sp.x in saline waters. Four species of anostracans (*B. denticulata, B. nichollsi, B. occidentalis, Streptocephalus* sp.) and two clam shrimp (*Limnadopsis birchii* and *Lynceus* sp.) are known from only one or two records each. Of the five clam shrimp species, *Caenestheriella packardi* was the most common in freshwaters and *Eocyzicus* sp. in hyposaline waters. *Triops 'australiensis'* was present as two forms difficult to differentiate except that one lives in fresh waters and the other in saline water up to 93 gL^{-1}. In addition to three saline species listed above, *B. simplex* is also a halophile (to 62 gL^{-1})(Table 4). Almost all of the species encountered generally live in very turbid waters, notable exceptions being *B. frondosa*, and also the saline species.

Nineteen of the 67 samples (28%) had co-occurring anostracans, and 12 (16%) had co-occurring clam shrimp species. The most common combination among anostracans was the *B. simplex* and the *Parartemia* n.sp.x (7 collections), and *B. australiensis* and *B. affinis* (5 collections). One collection (site 11 March 2003) had four species: *B. occidentalis, B. australiensis, B. affinis,* and *B. proboscida*. There were two collections with three species (*B. australiensis, B. halsei,* and *B. denticulata*, and; *B. australiensis, B. frondosa,* and *B. affinis*) and 16 between two species. Among spinicaudatans the common combination was *Caenestheria dictyon* and *Eocyzicus* sp. (7 collections), and on two occasions these two were joined by *Caenestheriella packardi*.

Habitatwise, four species (*B. simplex, Parartemia* n.sp.g, *Parartemia* n.sp.x, *Triops 'australiensis'* form b) were halobionts found only in hyposaline – hypersaline waters. These included lake and saline stream sites for *Parartemia* and *Triops,* but only lake sites for *B. simplex*. *Eocyzicus* n.sp. lived in both hyposaline and fresh waters, the later including only gypsum pans and turbid samphires. Among the freshwater species with two or more occurrences, *B. probiscida* was restricted to claypans, *B. halsei* to claypans and dams, *B. frondosa* to vegetated sites and freshwater creek pools, *Eulimnadia dahli* to vegetated pools and gypsum pans, *Caenestheria dictyon* to gypsum pans and samphires, while *B. australiensis, B. affinis* and *Caenestheriella packardi* lived in a variety of freshwater sites.

Discussion

At least 107 taxa of invertebrates were collected from these Carey wetlands. The list is incomplete because some groups (*e.g.,* chironomids, water mites) were not identified or hardly studied (*e.g.,* rotifers, littoral microcrustaceans) and because a limited array of wetlands were sampled on only four field trips. By comparison, there are about 500 species in the southern Carnarvon Basin (Halse *et al.* 2000) and about 1000 in the Wheatbelt (Pinder *et al.* 2004), both in Western Australia. It is difficult to know how much to attribute the relatively low number in the Carey wetlands to inadequate study, fewer wetland sites available, smaller geographic area or harsher environmental conditions. Concerning the latter factor, a similar inland area of the middle Paroo in eastern Australia has 200+ invertebrate species (Timms & Boulton, 2001), but it is larger and better studied, while the riverine waterholes of the huge Lake Eyre basin have only 136 macroinvertebrate species but over 400 microinvertebrate species (Costelloe *et al.*, 2004).

Whatever the reasons contributing to the apparent depauperate Carey wetlands, it is certain that most of the species present are hardy ones occurring throughout much of the arid zone (Halse *et al.* 2000, Timms & Boulton 2001, Pinder *et al.* 2004,). Examples include

Boeckella triarticulata, Daphnia carinata s.l., *Branchinella australiensis, Caenestheriella packardi, Austrolestes* spp., *Hemianax papuensis, Hemicordulia tau, Micronecta* sp., *Agraptocorixa* spp., *Anisops* spp., *Triplectides australicus, Berosus* spp., and *Eretes australis.* Signficantly absent are larger crustaceans requiring permanent water (e.g., *Cherax* spp., *Macrobrachium* spp., *Holothuisiana* spp.) or at least protected places for aestivating (amphipods, isopods).

Like the Carnarvon and Wheatbelt areas (Halse *et al.* 2000; Pinder *et al.* 2004) many species are known from few individuals collected only once. Besides a few zooplankton species such as *Latonopsis brehmi, Ceriodaphnia* sp., and *Trigonocypris globulosa* (Table 2), and an array of beetles (Table 3), this list includes many large branchiopods (Table 4). Of particular interest is the absence of *Branchinella apophysata* Linder whose type locality is within the study area.

With most wetlands visited twice in each wet season, there was some variation in species composition in each as the wetland developed after filling. Notably, as expected (Hancock & Timms 2002; Timms 2001), most large branchiopods were far more common soon after filling than later and vice-versa for beetles and odonates. In cases where wetlands have been visited in different years, there was usually no significant variation in species composition. Exceptions were the variable site 2 and Lake Carey.

Lake Carey had a somewhat different fauna when up to 40cm deep in March-April and 13 to 62 gL^{-1} (and up to 150 gL^{-1} near one mine discharge point) than when very shallow and much more saline (ca 55 to 230 gL^{-1}) in 1998–99 (Chaplin & John 1999; Ward 1999). *Parartemia* n.sp x, cyclopoid copepods and various ostracods occurred both times, but the less saline filling had *Moina baylyi, Branchinella simplex* and *Triops 'australiensis'* and the 1998 filling had *Daphniopsis pusilla.* Episodic saline lakes varying widely in salinity are well known to have different faunas at different salinities/seasons (Williams 1990; Timms 1998), which probably points to a further differentiated fauna when the lake is subsaline/hyposaline after a major fill (Chapman & Timms 2004; Coleman, Datson & Timms unpublished data).

The 19 species of large branchiopods in Carey wetlands (Table 4) include mostly common and widespread species, but a few are of local interest. The known distribution of *Branchinella nichollsi* is extended 200 km northwards (Timms 2002); early indications that this species is halophilic (Geddes 1981) are not supported by this occurrence from a gypsum pan of fresh water and another recent record from Lake Arrow near Kalgoorlie (Chapman & Timms 2004). On the other hand, the present records extend the known upper salinity limit of *B. simplex* from 21 gL^{-1} to 62 gL^{-1} making it the most salt-tolerant species in *Branchinella. Parartemia* n.sp.g is the same species of a similar notation used by A. Savage (pers.comm.) and in Timms (2004); its presence in the Carey area extends its distribution inland from the Carnarvon and Pilbara areas. *Parartemia* n.sp.x is a further new species beyond the eight being described by A. Savage (pers.comm.). Presently it is known only from Lake Carey and its inflowing saline streams; this brings to four the number of *Parartemia* species known from large salinas in inland Western Australia (Timms 2004; A Savage, pers.comm.), each with a limited geographic distribution. The repeated presence of *Triops 'australiensis'* in mesosaline and hypersaline water to 93 gL^{-1} (Table 4) confirms that a form of *Triops australiensis* is halophilic. Previously it had been raised from this lake in hyposaline water (10 gL^{-1})(Chaplin & John 1999). Its relationship to a superficially identical form in adjacent fresh waters is unknown.

The present study suggests a range of wetland types in the Carey catchment, with a basic divide between saline and fresh sites and among the later between turbid and clearer water sites. Highly variable hydrological patterns blur the borders between types because some sites behave differently depending on hydrological input. These same three factors, *i.e.,* salinity, turbidity, hydroperiod, are those important for invertebrate distribution and wetland assemblages in the Paroo (Timms & Boulton 2001) and are also important environmental drivers in the Southern Carnarvon district (Halse *et al.* 2000) and Wheatbelt (Pinder *et al.* 2004). Many of the wetland types, such as claypans, artificial dams, creek pools, salinas in the Carey area are distinguishable elsewhere in Western Australia (Halse *et al.* 2000; Pinder *et al.* 2004), and in other arid parts of Australia (e.g., Paroo, Timms & Boulton 2001).

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